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Development of a masking device to exclude contaminated reflection during tower-based measurements of spectral reflectance from a vegetation canopy

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ABSTRACT

Plant canopy spectral reflectance is measured at many observation towers to estimate the canopy's biophysical and physiological features. When a wide-angle downward-facing spectrometer is used for tower-based measurements of reflected irradiance, it also captures reflections from the tower and near-horizon light from the sky within the field of view, leading to incorrect canopy reflectance estimates. However, the effects of this contamination have not been quantified. Therefore, we developed a retractable masking device to allow more accurate measurement of canopy reflectance by excluding the contamination. We continuously observed canopy reflectance of a Japanese larch (*Larix kaempferi*) forest from a flux tower by using the device alternately in masked and unmasked modes. In this paper, we describe the design of the masking device and demonstrate how tower contamination affected the measured canopy reflectance. We found that the canopy reflectance in the visible spectral region was overestimated by a maximum of more than 3 times the actual value due to the tower contamination, but that the near-infrared reflectance was affected much less. The contamination effects were substantial and complex, and the magnitude varied depending on the wavelength, solar zenith and azimuth angles, weather conditions, and canopy phenological status. Consequently, vegetation indices calculated from the spectral data were greatly affected. For example, the contaminated Normalized Difference Vegetation Index was 8–22% lower than that obtained with the masking device. We conclude that to accurately measure canopy reflectance via wide-angle spectroradiometers or photosynthetically active radiation sensors, a masking device similar to the one described in this paper is strongly recommended.

1. Introduction

Understanding of the temporal and spatial variations in heterogeneous terrestrial ecosystems is becoming increasingly important to evaluate the global carbon budget in the context of climate change. For detecting and quantifying of these changes, satellite remote sensing is expected to be a useful tool, because it enables repeated non-destructive observations over wide areas, with adequate spatial and temporal resolution. The spectral features of plants have been investigated at a leaf, canopy, regional, or global scale to indicate the biophysical and physiological characteristics of vegetation, and various vegetation indices have been suggested (e.g., Rouse et al., 1974; Tucker, 1979; Gitelson and Merzlyak, 1994; Gitelson et al., 1996; Huete et al., 2002). For example, the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) have been widely used to estimate vegetation biomass, the fraction of absorbed photosynthetically active radiation (fAPAR), leaf area index (LAI), light-use efficiency, and gross primary production (GPP) (e.g., Asrar et al., 1989; Baret and Guyot, 1991; Goward and Huemmrich, 1992; Gamon et al., 1995; Myneni et al., 1997; Turner et al., 2003). These indices have been incorporated into terrestrial ecosystem models to estimate the regional and global carbon budget (Potter et al., 1999; Running et al., 2004; Xiao et al., 2004; Sasai et al., 2005; Sims et al., 2006).

To estimate the photosynthetic parameters and the carbon budget by upscaling from individual to regional or global scales, validation at a canopy scale is necessary based on precise measurements of canopy reflectance. Currently, carbon dioxide (CO_2) exchange between the atmosphere and terrestrial ecosystems is being measured at more than 680 CO_2 flux sites (Fluxnet, http://www.fluxnet.ornl.gov/). At many of the flux towers, spectral

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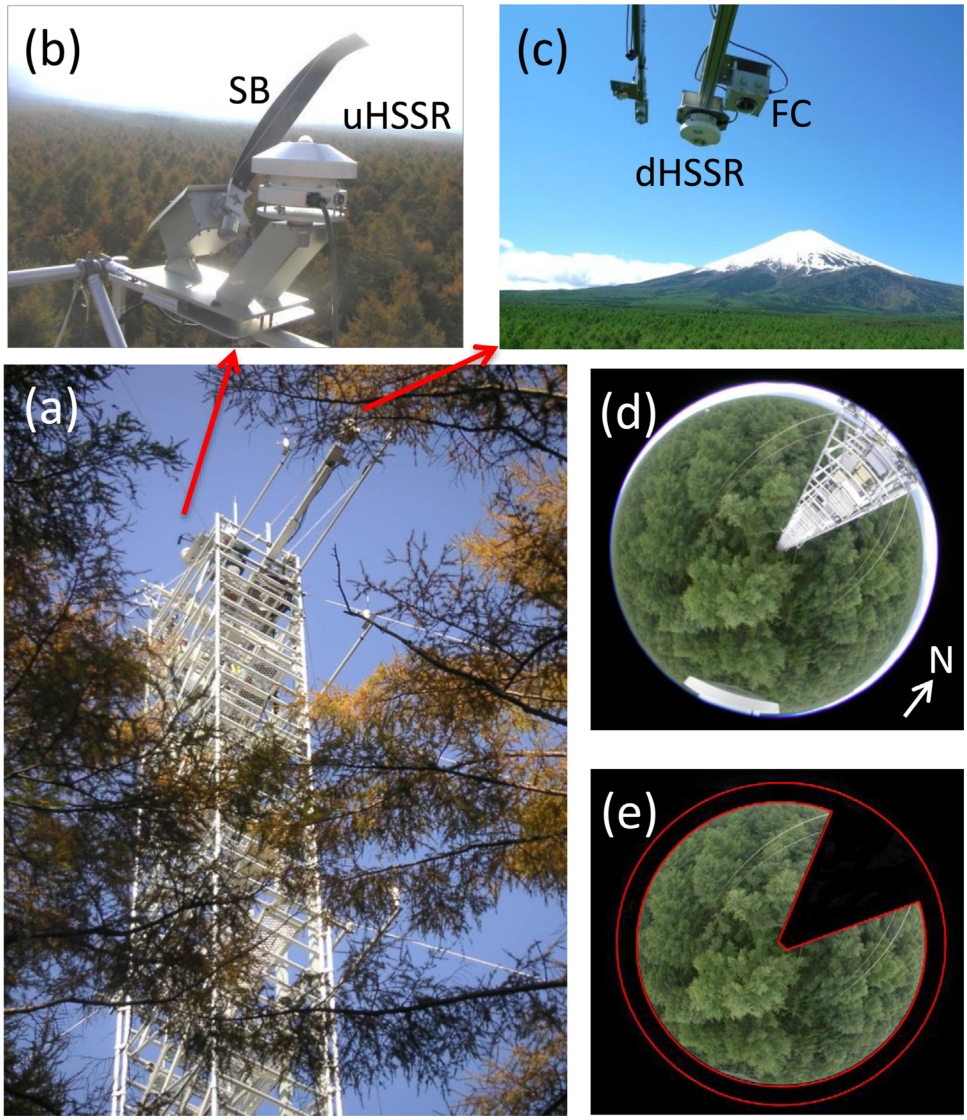

Fig. 1. Flux tower and the spectral measurement system. (a) The flux observation tower. (b) Upward-facing HSSR (uHSSR) with a shadow band (SB) on the top of the tower, at a height of 32 m. (c) Downward-facing HSSR (dHSSR) and a fish-eye lens camera (FC) on an arm that projects 2.1 m southward from the tower at a height of 30 m. (d) Conventional FOV for measurement of the outgoing irradiance. The tower and the near horizon sky are bright against the darker canopy. (e) Virtual image of the partial pure canopy obtained by masking out the non-vegetation area.

reflectance from the canopy and biological parameters are observed as well.

For effective integration of optical remote sensing with CO_2 fluxes and the biological characteristics of a canopy, the SpecNet spectral network was established at several flux sites in 2003 (Gamon et al., 2006). Plant canopy reflectance has been measured using PAR sensors, pyranometers, and multi-angle spectrometers to validate and improve the use of satellite remote sensing techniques (e.g., Cheng et al., 2006; Hilker et al., 2007; Hall et al., 2008). Similarly, the phenological eyes network (PEN; http://pen.agbi.tsukuba.ac.jp/index_e.html) was established in Japan in 2003. PEN focuses on phenology and has obtained continuous spectral observations of canopies using hyper spectroradiometers on flux towers at approximately 30 sites (Nasahara and Nagai, 2015). The derived tower-based reflectance data have been utilized in ground-truthing to validate satellite data, and to estimate phenological changes and photosynthetic parameters (e.g., Nakaji et al., 2008, 2014; Ide et al., 2010; Motohka et al., 2010, 2011; Nagai et al., 2010; Muraoka et al., 2013).

For such tower-based spectral measurements, wide-angle downward-facing spectroradiometers or PAR sensors are often used, because they provide a wider measurement footprint than narrow-angle sensors. However, they have a disadvantage: the tower that supports the instrument inevitably becomes part of the radiometer's field of view (FOV). This results in contamination of the tower-based reflectance by reflections from the tower and decreases the accuracy of measurements of canopy spectral reflectance. The problem created by this contamination has been recognized, and some researchers have tried to exclude the contamination using a simple linear mixture model based on the fraction of the image accounted for by the tower and the assumption of the constant reflectance from the tower (Motohka et al., 2011). Although this method might derive an approximately corrected reflectance, it does not account for diurnal and seasonal variations in the tower's contamination effect. The spectral reflectance from the tower is too complicated and too tower- and site-specific to simulate. In addition, hemispherical sensors are likely to capture some near-horizon light, which can also affect the